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TITLE ACCELERATION OF POLARIZED PROTONS IN AHF

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Acceleration of Polarized Protons in AHF

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In this paper I perform an analysis of the depolarization expected during acceleration from 0.8–45.0 GeV kinetic energy in the Advanced Hadron Facility (AHF) accelerators. This work parallels closely the treatment in the LAMPF II proposal.[1]

The depolarization mechanisms are taken to be the so-called (i) intrinsic and (ii) imperfection resonances. These resonances are expected when the spin tune ν_{sp} assumes certain values. The spin tune $\nu_{sp} = G\gamma$ where G is the anomalous magnetic moment (1.7928 for protons) and γ is the ratio of the particle total to rest-mass energy. The intrinsic resonances occur for $\nu_{sp} = mS \pm \nu_y$ where m is a positive integer, S is the machine superperiodicity, and ν_y is the vertical betatron tune. The imperfection resonances occur when ν_{sp} is integral. The physics and treatment are well documented.[2]

I wrote a program to evaluate the depolarization that occurs for an adiabatic passage of an accelerated beam through a resonance. The Froissart-Stora equation[3] yields a simple relation for the ratio P_f/P_i where

$$\frac{P_f}{P_i} = 2exp(-\pi^2|\varepsilon|^2/2\alpha) - 1 \tag{1}$$

In Eq. (1) P_f (P_i) is the polarization long after (before) passage through the resonance. The quantity α is the crossing speed and is given by

$$\alpha = \frac{1}{2\pi}(G\Delta\gamma - \Delta\nu_0), \tag{2}$$

where $\Delta\gamma$ and $\Delta\nu_0$ are the changes in γ and ν_0 per turn during acceleration. There are two ways to avoid depolarization: either one quickly crosses a weak resonance $|\varepsilon|^2/\alpha << 1$ or slowly crosses a strong resonance $|\varepsilon|^2/\alpha >> 1$, in which case the spin will be totally flipped. The depolarization resonance width ε is given by [2]

$$\varepsilon(\nu_{sp}) = \frac{1}{2\pi}\int_o^{2\pi} \xi(\theta)e^{-i\nu_{sp}\theta}d\theta, \tag{3}$$

where $\xi(\theta)$ is a function of the spin tune, magnet lattice, and the vertical excursion of the beam. The form of Eq. (3) is a Fourier amplitude, and $\varepsilon(\nu_{sp})$ will be significant if $\xi(\theta)$ contains frequencies that coincide with ν_{sp}.

In calculating ε for intrinsic resonances one uses the vertical size resulting from betatron oscillations; similarly the vertical closed-orbit distortion arising from magnet misalignments is used to evaluate ε in the case of the imperfection resonances.

The data for the two AHF accelerators are given in Table 1. The acceleration waveform for the booster is a sine wave of frequency $f_a = 42.55$ Hz. Therefore $\Delta\gamma$ varies during the acceleration (from t=0 to t=11.75x10^{-3} sec) $\Delta\gamma$ = 8.5126x10^{-4} sin(267.3495t). The main ring is ramped up linearly for 50 msec so the main ring $\Delta\gamma$ = 36.745x10^{-4} (a constant).

The depolarizations were obtained using Eq. (1) for both the booster and main ring. The booster results for both the intrinsic and imperfection resonances are shown in Fig. 1. The abscissa is plotted in units of ν_{sp}. The ten solid vertical lines represent the imperfection resonances for an assumed rms vertical magnet misalignment error σ_y of 0.2 mm. The three dashed lines represent the ranges of depolarization expected for the $\nu_{sp} = \nu_y$, $12 - \nu_y$ and $6 + \nu_y$ intrinsic resonances, respectively. The ranges correspond to the differences in vertical beam size associated with normalized transverse emittances from 4.67–23.33 mm-mr. This interval corresponds to 3-15 mm-mr geometric emittance at 797 MeV; this range approximates what we can reasonably expect for an injection phase space.

The low superperiodicity ($S = 2$) and large energy variation in the main ring insure a large number of resonances: 75 intrinsic and 74 imperfection resonances are crossed during the 50 msec acceleration period. The above calculations were repeated for the main ring. Fig. 2 shows the P_f/P_i plot for the imperfection resonances assuming the rms error $\sigma_y = 0.2$ mm. I show separately the results for the 75 intrinsic resonances in Table 2. The results are tabulated for both the values of normalized emittance that we have considered. In this case I do not enumerate the P_f/P_i values for individual resonances. To summarize, the booster is probably all right in regard to maintenance of polarization during the 11.75 ms acceleration time. Careful alignment of components and judicious use of harmonic correction dipoles should reduce effects due to imperfection resonances. Tune-shifting quadrupoles can be used to either speed up or slow down passage through intrinsic resonances. All of these techniques have been proven at the Brookhaven AGS and at Saclay.

The main ring situation is more severe: the imperfection resonances do not appear serious but the intrinsic resonances are quite pronounced as indicated in Table 2. I would say that the only hope at present is through introduction of Siberian Snakes in the main-ring long-straight sections. These alternatives are under active consideration for the other kaon factory proposals.

References

1. "The Physics and a Plan for a 45-GeV Facility That Extends the High-Intensity Capability in Nuclear and Particle Physics," Los Alamos National Laboratory LA-10720-MS, May 1986.

2. E. Courant and R. D. Ruth, Bookhaven National Laboratory Report 51270, 1980.

3. M. Froissart and R. Stora, Nuclear Instruments and Methods 1, 297, 1960.

AHF

Table 1: Machine Parameters

Parameter	Booster	Main Ring
Energy Range (GeV)	0.797-6.0	6.0-45.0
Superperiods (S)	6	2
Circumference (m)	330.82	1323.32
Vertical Tune ν_y	4.28	6.45
Repetition Rate (Hz)	60	3 1/3

Table 2: P_f/P_i Results for the Main Ring

P_f/P_i Interval	Number	
	Normalized Emittance = 4.67 mm-mr	Normalized Emittance = 23.33 mm-mr
>0.98	68	39
0.96-0.98	4	9
0.94-0.96	1	11
0.92-0.94	1	6
0.86-0.92	1	4
<0.86	0	6

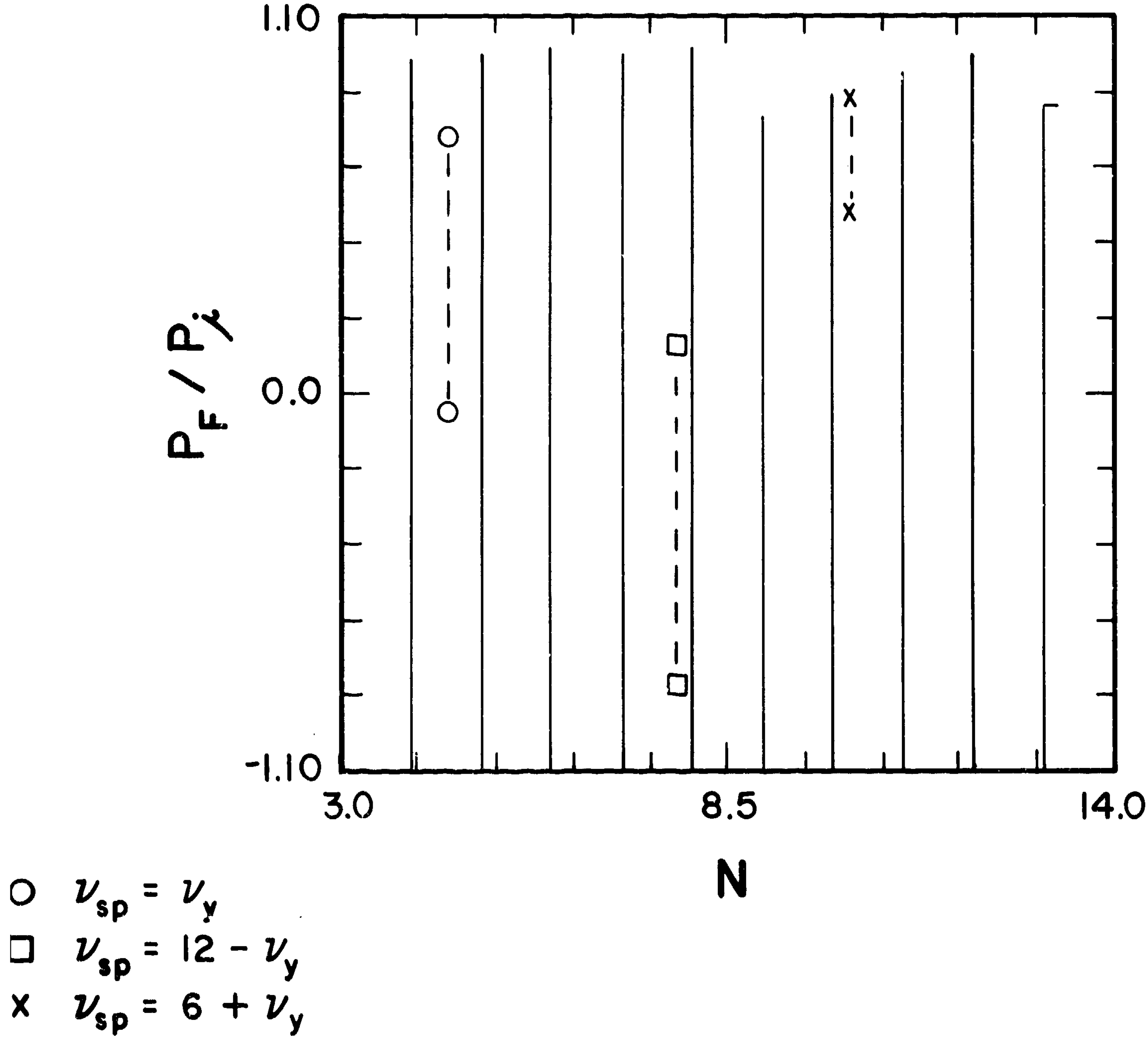

Figure 1: Calculated values of P_f/P_i obtained using Equation (1) for the AHF booster. The solid lines represent the imperfection resonances. The dashed lines represent the ranges of the three intrinsic resonances.

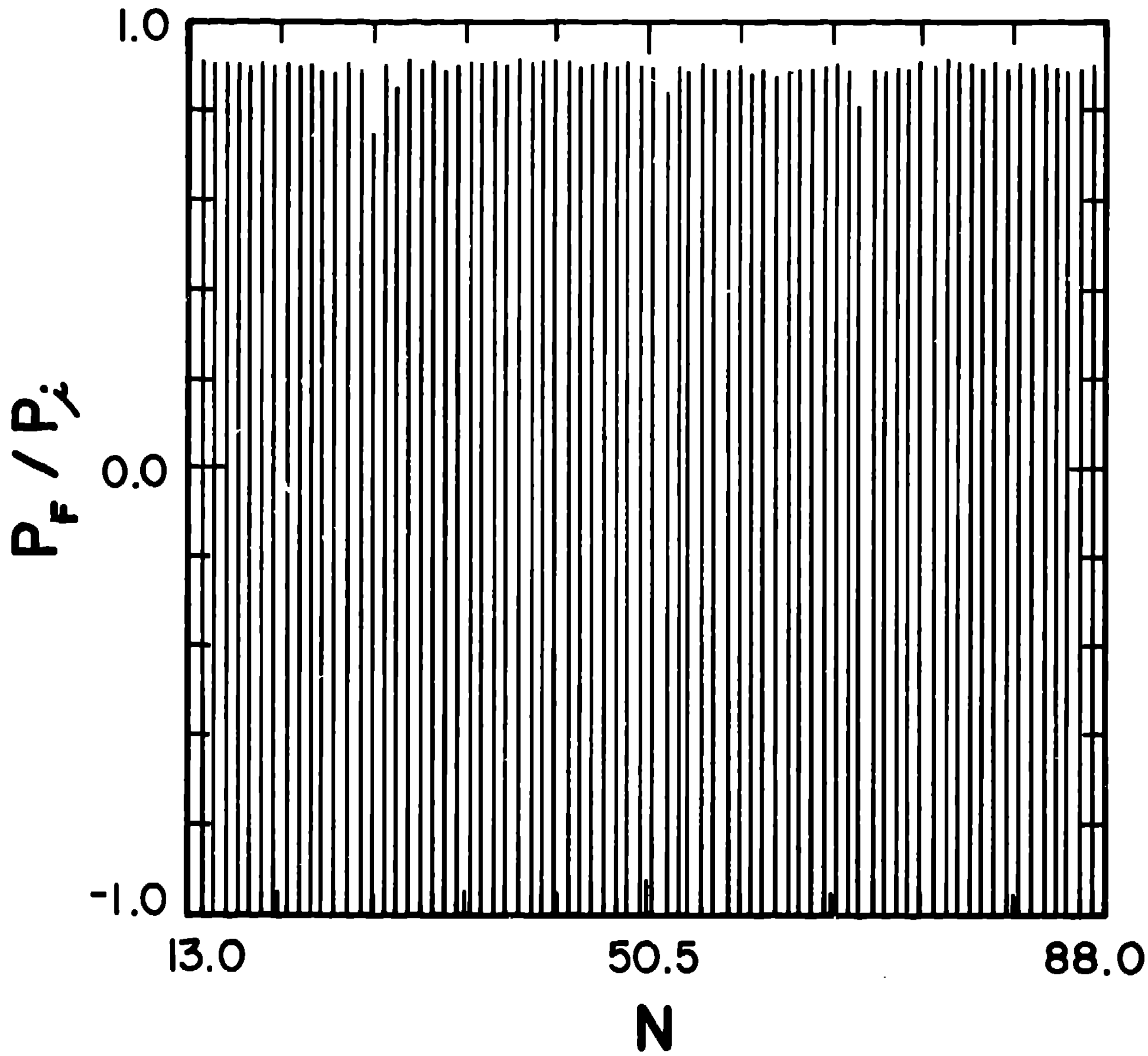

Figure 2: Imperfection Resonances In The Main Ring